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# Final Project Report

**Project Title:** Workshop on Advances in Scientific Computation and Differential Equations '93 (SCADE)

**PI/PD Name and Address:** Gene H. Golub
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**Date:** July 8, 1994

The above referenced conference was held in Auckland, New Zealand, z January 3 – 8, 1993. Previous meetings have been held in Europe and North America. The next one will be in the United States. With the aid of the Office of Naval Research (ONR) grant, a large contingent from the United States was able to participate. This included the following:

Ken Atkinson, University of Iowa

Steve Campbell, North Carolina State

Tony Chan, University of California at Los Angeles

Ian Gladwell, SMU [what is SMU???]

Alan Hindmarsh, Lawrence Livermore Laboratory

Z. Jackiewicz, Arizona State

B. Leimkuhler, University of Kansas

Robert O'Malley, University of Washington

Linda Petzold, University of Minnesota

Rosie Renaut, Arizona State

Robert Russell, Simon Fraser University

Bob Skeel, University of Illinois

I have taken the liberty of attaching the (edited) report of Dr. David Kahaner of the ONR/NSF office in Tokyo. He has described some of the highlights of this meeting. My own personal feeling is that this meeting was too narrowly focused on traditional methods for solving ODEs. This was in part because of the strong influence of John Butcher. Nevertheless, it was a meeting/workshop of unusually high quality and there was much enthusiasm amongst the participants.

Gene H. Golub

## From Kahaner's Report

One hundred fifty overseas participants from 24 countries converged on Auckland to honor Professor John Butcher on his 60th birthday and to survey the latest research in numerical methods for ordinary differential equations (ODEs). Butcher was one of the first researchers to study and thoroughly analyze the structure of Runge Kutta methods for solving ODEs. Conferences on ODEs have been independently organized at least since the early 1970s, and many participants have met repeatedly.

Although the subtitle of SCADE was general "scientific computing" and there were a significant number of papers on non-ODE topics, SCADE was primarily a forum for exchanging new ideas on the current state of research in ODEs. (For example, a very well done presentation by Sloan surveying lattice rules for multidimensional quadrature seemed mildly out of place, even to Professor Sloan.) And since Butcher was a primary developer of Runge-Kutta methods, these dominated the numerical methods that were discussed. In that sense SCADE was much more like a small workshop than a large conference, and in fact, many of the participants had met previously at related meetings in the United States or EC [what is EC???].

For most of the talks, the main content was theoretical numerical analysis, with Runge-Kutta methods naturally receiving the dominant emphasis, in honor of John Butcher. But quite a few talks were concerned with algorithmic and software issues; several focused on applications. The vast majority of talk topics concerned initial value problems, in accordance with both Butcher's work and the tradition of this series of meetings, but a few talks were on boundary value problems for ordinary differential equations. Although computing is an integral part of numerical methods for ODEs. Butcher and his colleagues are primarily analyzing ODE methods. All the computing platforms that I saw were PCs or modest Unix workstations. I visited the Defense Science Establishment in Auckland. Essentially all their computation is PC-based, but Professor Butcher informs me that the computing facilities in the University of Auckland, Mathematics Department are much better than in most United States Mathematics Departments, although they do not have easy access to supercomputers.

With so much international participation, it is only appropriate to assess progress in numerical ODEs in a global setting. It should be understood that Butcher's work resulted in a flowering of research in Runge Kutta methods. It is very likely that there would not have been as many significant subsequent developments in this area without his early papers to build upon, or at least they would have been much later in appearing. His students and colleagues have taken the field in many new directions, and although the actual number of New Zealand scientists contributing is modest, their impact has been huge.

At SCADE, the talk by Hairer included a survey on the connection between trees and Runge Kutta methods for ODEs, the topic initiated by Butcher and now universally called Butcher trees. Most of Hairer's talk was devoted to new results on backward error analysis for symplectic integrators. Butcher himself is very modest about all this, and attributes the idea to Merson, and perhaps even to Gill. Recently, however, his research interests have moved on to diagonal implicit multistage integration methods (DIMSIM), some of which he claims are suitable for parallel implementation.

The numerical methods spotlight usually beams on partial differential equations (PDEs) and their applications. ODEs are thought of as easier, and, to many in the engineering community, as a solved problem. While there is no doubt that the curse of dimensionality makes PDE problems very demanding, the fact that engineers can formulate and solve ODEs is an indication of the reliability of the software and the strength of the underlying theory. Thus it might seem that there are no major problems left to work on, and that the research community is mostly engaged in fine tuning. It is true that a number of SCADE papers were related to refinements and extensions, such as extremely high order methods, roundoff error analysis, extrapolation, etc.

There is also work on software (for example, see the papers by Krogh, Delves, Thomsen, Broughan, and Gladwell) including questions of Fortran 90, C++ object oriented implementations, and experimentation with solvers on parallel computers. But to the extent that these only marginally extend the kinds of problems that can be solved, they need to be included in the category of refinements too, although it is clear that just such incremental improvements are exactly what the engineering community desires. (For example, there are continuing discussions on the advantages of reverse over forward communication for ODE solvers, e.g., see Gerlach's paper on STRIDE. Reverse communication provides more control to the calling program, and this can be helpful when interfacing an ODE solver with other software, such as a sparse matrix package.)

Nevertheless, it was exciting to observe that there are several new and fascinating directions that are being developed that have the potential to significantly enlarge the class of problems that can be solved.

Traditional ODE problems specify a differential equation and initial condition, usually written as follows:

$$y' = f(y); \quad y(t0) = y0$$

The solution is requested on some interval, $y(t)t0 \leq t1$. (It is known that, if $f$ is smooth, the differential equation and initial condition are necessary and sufficient to determine the solution in an interval around $t0$.)

A number of years ago a major step was made when scientists began to consider "implicit" ODEs, wherein the derivative was not explicitly available. Such equations are of the form,

$$f(y, y') = 0$$

and are usually called differential algebraic ODEs (DAEs). (Some important early research on this topic was by L. Petzold.) Both theoretically and in terms of implementation, this is a much more difficult problem than the original, but a variety of papers have studied this topic and software is beginning to appear (see for example the papers of Campbell, Jay, Marz, and Watanabe).

Also, it is worth noting Krogh's discussion on plans for a new package based on multistep methods for stiff systems with extensions to DAE and delay systems. U. Ascher described new collocation software for boundary value DAEs.

Finally, I note that every meeting produces some papers that present really different approaches. At SCADE, one such was by T. Watanabe. The author presented a scheme (and software, HIDMDV and HIDMEG) for DAEs including eigenvalue problems, which is claimed to be able to solve a wide variety of problems with very smooth step-size control. Since Watanabe is not well known in the

West, I have sent several copies of his papers to Western colleagues who can make a a careful examination of his results.

An old idea that finally seems to have reached critical mass is that of delay differential equations (DDEs). The essential point to note about ODE initial value problems is that they have no "memory," the equation and the initial condition completely specify the solution. In many physical systems, especially those in biology, or other large scale slowly responding systems, the inclusion of some history is natural (the solution now depends on the system state yesterday, etc.). One form of the DDE (not the most general) follows:

$$\begin{aligned} y'(t) &= f(t, y(t), y(t - z(t, y(t)))), \quad t \geq 0 \\ y(t) &= y_0(t), \quad t \leq 0 \end{aligned}$$

(Examples of a DDE are $y'(t) = y(t)[1 - y(t-1)]$, or $y'(t) = y(t/2)$.)

While many authors have realized the importance of such problems, until very recently there has not been reliable software; this is rapidly changing as DDEs are being better understood. Initially this involves refinements to existing ODE packages. While this has been successful to some extent, more specialized programs are appearing too. For an outstanding example of DDEs in practice, see the papers by Bocharov (Institute of Numer. Math., Russian Academy of Sciences, Moscow, but currently on leave from there and working with Butcher in Auckland). Bocharov and colleagues have studied models of human immune response during viral infections (flu, measles, polio, hepatitis, etc.) leading to systems of ten nonlinear DDEs for the time evolution of the state variables. This is really part of a parameter identification problem.

In addition to having to solve the equations, the authors are seeking to fit various parameters so that the model approximately reproduces given experimental data. Thus, solving the equations needs to be done iteratively; the authors employ a combination of the simplex and Quasi-Newton methods. To assist with their research, they have developed a DDE version of the (old) DIFSUB, originally written by Gear, as well as a DDE version of the well known RKF45, and compared these on a representative set of stiff and non-stiff test DDEs. Taken as a whole, this is impressive work which also shows how important DDEs can be and suggests many other application areas (Russian scientists continue to make major contributions to the ODE field; see also the paper by Shirkov on Rosenbrock Runge Kutta Schemes.)

My own assessment is that the development of tools such as those above for solving DDEs will fuel the creation of models involving delays within the engineering world. Today, DDEs are not normally proposed, but I suspect that there will be a move to do so as the software enters the mainstream. The paper by Baker gives a brief survey of the issues related to solving DDEs and Petzold even considers delay differential algebraic equations (DDAEs), but these seem a bit further over the horizon. There are still formidable theoretical problems to be studied, for example, see the paper by A. Iserles concerning DDEs in which the delay is not constant but time and solution dependent, or the discussion by R. O'Malley on regularization techniques (allowing the use of singular perturbation theory).

Another topic with a long history that finally seems to be nearing practical usefulness is that of stochastic differential equations. In these, one or more element within the equation is a random variable, often a Wiener process. Papers at SCADE by Mitsui, Saito, and Platen consider this problem. Some traditional techniques from ODE theory can be extended to this situation (Runge Kutta, Taylor Series, rooted trees, etc.), but typically deep analytic tools are required. Some of this work dates to the 1960s or earlier, for example, the Wong-Zakai approximation. But an exciting development, indicating the maturation of the topic is the announcement of the book by Platen, "Numerical Solution of Stochastic Differential Equations," Springer, 1992, written for undergraduate science and engineering students and containing over 100 PC-based computational exercises.

There were a few papers on parallel computation in the solution of ODEs. Kevin Burrage gave a nice survey of the work in this area. Parallelism in ODEs can usually be classified into (a) parallelism across the method, (b) parallelism in space, and (c) parallelism in time. Burrage believes that an efficient parallel algorithm might have to take elements from all three categories. Although there are many splitting methods (see, for example, the paper by Cooper and Vignesvaran on Runge Kutta or that of Skelboe using the implicit Euler method), there have not been many successes except when applied to linear problems. A potentially fruitful new approach is waveform relaxation, and this topic was addressed by A. Bellen in the context of PDEs. Butcher's recent work on DIMSIM also looks hopeful. F. Mazzia considers transforming the initial value problem to a boundary value problem to take advantage of parallel opportunities associated with the linear algebra.

L. M.Delves gave an informal talk about his experiences developing "architecture resistant" parallel algorithms for software libraries, 30-person years of work that has been going on over the past four years (the project sounded very much like Zipcode). Delves also bemoaned the paucity of compilation-level tools to accomplish effective parallel data and task distribution. T. Chan described parallel methods for solving linear systems, but this topic rightly has applications to PDEs more so than ODEs.

A research area in which New Zealand and Australia has been particularly strong is symbolic computation. One of the most interesting applications of this has been the development of SENAC (A Software Environment for Numeric and Algebraic Computation), primarily through the efforts of Kevin Broughan of the Waikato (New Zealand). Current work has resulted in a SENAC interface to the NAG Library and to the ODE routines in environments. Broughan is having difficulties attracting users, who are often fearful of spending time learning a new skill unless there is a demonstrable benefit to them. (My recommendation was to focus on a particular application area and develop problem solving tools for that first.) It is clear however, that the merging of numeric and symbolic computation is becoming increasingly important. Another step in that direction was Thomsen's paper on the status and plans for a package called Godess in C++ that will combine SDIRK methods with graphics interfaces.

Peter Albrecht's talk concerned an alternative approach to analysis of Runge Kutta methods without trees. The talks by Söderlind, on nonlinear iterations in ODE solvers, and by Cash on MEBDF methods, both described some useful algorithmic ideas that are highly relevant to stiff ODE software.

As mentioned, ODEs were the major theme of SCADE, but some other topics were also presented. Greenspan gave a more narrowly focussed but very interesting paper on difference schemes for Newtonian and special relativity dynamics systems that obey discrete conservation laws. Ian Sloan and colleagues were well represented in papers on lattice rules for quadrature and in applications to integral equations. (K. Atkinson described his new software package for boundary element methods.)

A very interesting paper that was not directly related to differential equations at all was that of Olavi Nevanlinna, on the dynamics of Krylov methods, in which he described sublinear, linear, and superlinear phases of Krylov iteration sequences. Physical applications were not much in evidence.

This was not really a modelling conference, and those few that were presented were small- to medium-sized without extensive use of computing platforms. One exception, was the paper by A. Hindmarsh on oil shale modelling using the method of lines both for ODEs and DAEs. (The author's institution, Lawrence Livermore Laboratory, is well known for its extensive computing resources.)

At the close of the conference, there was a discussion of ideas for the next meeting in this series. A tentative decision was made to hold it at Stanford in March 1995, in honor of C. W. (Bill) Gear's 60th birthday. According to Gene Golub, that plan is now definite.

# TITLES AND AUTHORS OF PAPERS PRESENTED AT SCADE'93

OFFICIAL OPENING
Dr Horst W. Geriach, conference secretary
Professor Alastair J. Scott, Head, Department of Mathematics and Statistics
Professor Peter L. Bergquist, Deputy Vice-Chancellor, University of Auckland

OPENING LECTURE, introduced by Professor Kevin Burrage of the Department of Mathematics, University of Queensland.
John Butcher: Some aspects of numerical ordinary differential equations

PLENARY LECTURE
R. E. O'Malley Jr and L. V. Kalachev: Regularization of differential - algebraic equations

PARALLEL SESSIONS
Stephen L. Campbell: Numerical methods for unstructured nonlinear higher index DAEs
Tony F. Chan: Parallel iterative algorithms for elliptic problems
Reinhold von Schwerin: An inverse dynamics ADAMS-method for constrained multibody systems
Horst W. Gerlach: An adaptation of STRIDE for large sparse problems

PARALLEL SESSIONS
Laurent Jay: Convergence of Runge-Kutta methods for differential-algebraic systems of index 3
Christina C. Christara: Schwarz splitting and spline collocation for elliptic PDEs
Ray Zahar: Condition preserving methods for staircase systems
John R. Dormand: Globally embedded Runge-Kutta methods for ODEs

PLENARY LECTURE
Peter Deuflhard: Adaptive discrete Galerkin methods for macromolecular processes

PARALLEL SESSIONS
Morten Bjorhus: Dynamic iteration for hyperbolic PDEs
P. J. van der Houwen and B. P. Sommeijer: Butcher-Kuntzmann methods and parallel computers
William McLean: Numerical integration for boundary element methods
Tertia Ann Stock: The behaviour of iterative techniques in epidemiological and telecommunication modelling

PARALLEL SESSIONS
Irfan Altas and Kevin Burrage: A high accuracy defect correction multigrid method for incompressible Navier-Stokes equations
A. Bellen: Parallel waveform relaxation
Thanh Tran: The K-operator and the boundary element-Galerkin method for a boundary value problem
Arasaratnam Arasilango: Design of an Intelligent Teaching Interface for Biological Classification Schemes

PLENARY LECTURE
Roger Alexander: Stability and convergence of numerical methods for stiff initial value problems

PARALLEL SESSIONS
J. Cooper and R. Vignesvaran: Implementation of implicit Runge-Kutta methods on parallel processors
Timo Eirola and Luca Dieci: Positive definiteness in the numerical solution of Riccati and Lyapunov equations
Carolyn Dyke: Multigrid methods for partial differential equations on the MASPAR
Andrew Gill: Finite difference and discrete ordinate methods: application to a stability problem

PARALLEL SESSIONS
Stig Skelboe: Methods for parallel integration of stiff systems of ODEs
Stefan Vandewalle: Multicomputer solution of parabolic problems
Rosemary Renaut: Two-step Runge-Kurta methods for PDEs
E. B. Weinmuller, P. Szmolyan, W. Linzer and K. Ponweiser: Numerical simulation of a natural circulation steam generator

PLENARY LECTURE
Kevin Burrage: Parallel methods for systems ODEs

PARALLEL SESSIONS
Marino Zennaro: Stable multistep interpolants of Runge-Kutta methods
Per Grove Thomsen: SIMPLE - 2000 - implementation of ODE software
Lawrence Lau: Adapting scientific applications for parallel computation
Ivar Lie: Domain decomposition and efficient time integration for wave propagation problems

PARALLEL SESSIONS
Michail Diamantakis: Towards efficient implicit Runge-Kutta formulae for stiff ODEs
Ian Gladwell and Richard Brankin: A Fortran 90 ODE Code
L. M. Delves: The design of architecture-resistant parallel algorithms for numerical libraries
R. P. K. Chan: Symmetrizers for Lobatto IIIA methods

PLENARY LECTURE
Linda R. Petzold: The numerical solution of delay-differential-algebraic equations

PARALLEL SESSIONS
S. J. Thomas and R. V. M. Zahar: Subspace projection methods for differential systems
Romeo Tirani: Defect control in continuous Runge-Kutta methods by parallel computers
A. Papini, M. G. Gasparo, M. Macconi and B. Morini: Numerical solution of singularly perturbed quasilinear problems by parallel difference methods
E. Balakrishnan: Computational methods for quadratic function approximation

PARALLEL SESSIONS
Olavi Nevanlinna: Dynamics of the Krylov-methods
David A. Voss: Parallel MIRKs for stiff ODE
F. Mazzia: Parallel solution of ODE by using BVM methods
Bojan Orel: Symmetric pz-restricted approximants to the exponential function

PLENARY LECTURE
Donald Greenspan: On computer physics

PARALLEL SESSIONS
M. N. Spijker: Error analysis of Newton iteration in implicit Runge-Kutta methods
C.-S. Chien, W.-C. Lee and E. L. Allgower: On bifurcations of corank greater than two
David Stewart: Numerical methods for dynamic friction problems
W. Liniger and F. Odeh: On the numerical treatment of singularities in solutions of Laplace's equation

PARALLEL SESSIONS
Anne Kvaerno: The order of Newton type iterations for Runge-Kutta methods
Garry J. Tee: History of mathematics in New Zealand
Astrid Hols- ed: Computation of diagenetic processes in sedimentary basins
Kevin A. Br ghan: Symbolic-numeric ODEs and finite elements

PLENARY LECTURE
Christopher T. H. Baker: Issues in the numerical solution of delay-differential equations

PARALLEL SESSIONS
Karel in 't Hout The stability of theta-methods for systems of delay differential equations
Ross Wright: Mesh adaptation for two-point boundary value problems
David L. Clements: A boundary integral equation for the numerical solution of a second order elliptic PDE with variable coefficients
P. Amodio: BVM methods for ODE

PARALLEL SESSIONS
L. Torelli, R. Vermiglio and V. B. Kolmanovskii: Stability of some delay differential equations
Alan L. Andrew: Asymptotic correction of computed eigenvalues of differential equations
Thang Cao: The adaptive Galerkin method for integral equations of the first kind with logarithmic kernel
Hideko Nagasaka and Makoto Murofushi: The relationship between the roundoff errors and Moller's algorithm in the extrapolation method

PLENARY LECTURE
P. Shirkov: L-d ·emented Rosenbrock schemes with complex coefficients for stif ODE

PLENARY LECTURE
Kendall E. Atkinson: A boundary element package for Laplace's equation

PLENARY LECTURE
Arieh Iserles: Numerical analysis of delay differ tial equations with variable delays

PARALLEL SESSIONS

Hermann Brunner: The numerical solution of neutral Volterra integro-differential equations with delay arguments

Roswitha Marz: Progress in handling differential algebraic equations

T. Basaruddin: Practical stability bounds of difference methods for moving boundary problems

Maria Isabel Coutinho Vieira: Block explicit Runge-Kutta formulae for IVPs

PARALLEL SESSIONS

Bruce V. Riley: Numerical solution of the generalized Abel integral equation based on sinc approximation

Tsuguhiro Watanabe: A new numerical scheme to solve algebraic-differential equations

Song Wang: An exponentially fitted finite volume method for a singularly perturbed advection-diffusion equation

G. V. Mitsou and T. E. Simos: High order P stable methods with minimal phase-lag for the numerical solution of two-point BVPs with oscillating solutions (presented by Taketomo Mitsui)

PLENARY LECTURE

Syvert P. Norsett and Arieh Iserles: Biorthogonal polynomials in numerical ODEs

PARALLEL SESSIONS

Eckhard Platen: Numerical methods for stochastic differential equations

Miguel Scotter and Adrian Swift: Path-following experiences with simple combustion models

Z. Jackiewicz: Implementation of general linear methods for ODEs

K. Brenan: DAE issues in the direct transcription of path constrained optimal control problems

PARALLEL SESSIONS

Yoshihiro Saito and Taketomo Mitsui: B-series in the Wong-Zakai approximation for stochastic differential equation

Todd E. Peterson: Space time finite element methods for time dependent PDEs

Roland England: SYMIRK: an implementation of a symmetric implicit Runge-Kutta method with a multistep predictor

Alan C. Hindmarsh: ODE and DAE systems in oil shale models

PLENARY LECTURE

Ernst Hairer: Trees, a survey

PARALLEL SESSIONS

Masao Igarashi: Computational efficiency of Newton-Raphson like methods for algebraic equations

Zbigniew Leyk: Modified conjugate gradient method for nonsymmetric systems of linear equations

Robert D. Skeel: ODE methods for molecular dynamics

Basem S. Attili: Computation of generalized turning points using collocation at Gauss points

PARALLEL SESSIONS

Kjell Gustafsson and Gustaf Soderlind: Control strategies for the iterative solution of nonlinear equations in ODE solvers

K. Dekker: Preconditioned CG-type methods in the solution of time-dependent PDE's

Brynjulf Owren and Kenneth R. Jackson: Stepsize reduction in explicit Runge-Kutta methods when solving stiff constant-coefficient linear ODEs having nonnormal coefficient matrices

Florin N. Diacu: On Painleve's conjecture of celestial mechanics

PLENARY LECTURE

Uri M. Ascher and Ray Spiteri: Collocation software for boundary value differential-algebraic equations

PARALLEL SESSIONS

Vidar Thomee: Approximate solution of ODEs in Banach space - rational approximation of semigroups

John A. Belward: Numerical problems in synthetic aperture radar

Tomasz Jekot: Variational spectral method for nonlinear thermoelastic two-layer structures

Marianne von Schwerin and Hans Georg Bock: A trust region method for solving optimal control problems

PARALLEL SESSIONS

Michel Crouzeix: An algebraic proof of a von Neumann theorem

Song Xu: A new mathematical model of the synchronous generator convertor system for digital simulation

Toshiyuki Koto: Explicit Runge-Kutta schemes for evolutionary problems in PDEs

Helmut Maurer: Sensitivity analysis and shooting methods for parametric boundary value problems and nonlinear control problems

PLENARY LECTURE

Fred T. Krogh: An algorithmic look at issues in the design of a multistep code

PARALLEL SESSIONS

Richard J. Charron and Min Hu: Contractivity properties of linear implicit multistep methods

A. R. Humphries and A. M. Stuart: Numerical approximation of dissipative systems and attracters by Runge-Kutta methods

P. W. Sharp: Numerical solutions to a model for the transport of magmas in the Earth's crust and mantle

PARALLEL SESSIONS

Kazufumi Ozawa: Order barriers for Adams-type linear multistep multiderivative methods with non-negative coefficients

J. Schneid: Orthonormal wavelet bases

Tomonori Kouya and Masao Igarashi: The comparison of Moller and Gill methods for Runge-Kutta methods

PLENARY LECTURE

G. A. Bocharov and A. A. Romanyukha: Numerical treatment of initial value identification problems for delay-differential systems arising from immune response modelling

PARALLEL SESSIONS

Peter Albrecht: Consequences of a linear approach to Runge-Kutta methods

Desmond J. Hig` \m: Sensitivity issues in numerical linear algebra

Mohamed bin Suleiman and Saiman Mat Baok: Progressive partitioning: relationship between eigenvalues of Jacobian of ODEs and nonconvergence of iteration

PARALLEL SESSIONS

J. H. Verner: The continuing evolution of explicit Runge-Kutta pairs, or, When will we stop deriving them?

Bert Pohl: A comparison result for multi-splitting methods

Ben Leimkuhler: Numerical methods for constrained Hamiltonian systems

PLENARY LECTURE

Hans J. Stetter: Sensitivity analysis of algorithms in computer algebra

PARALLEL SESSIONS

J. R. Cash: MEBDF methods for stiff initial value problems

Bertil Gustafsson nd Per Lotstedt: Similarities between the GMRES method and Runge-K ta methods for first order PD

William Norrie Everitt: Regular approximation of ngular Sturm-Liouville problems

Robert D. Russell: Unitary integrators, applications to continuous orthonormalization techniques, and computation of Lyapunov exponents

PARALLEL SESSIONS

John Carroll: A matricial exponentially fitted scheme for the numerical solution of stiff initial-value problems

T. N. Langtry: Determination of good rank 1 simple lattice quadrature rules

Anton Zettl: Computing continuous spectrum of singular Sturm-Liouville problems

Fred Chipman. Paul Muir and Kevin Burrage: The maximum order of an s-stage mono-implicit Runge-Kutta method cannot exceed s+1

PARALLEL SESSIONS

A. M. Stuart: An analysis of local error control for dissipative, contractive and gradient dynamical systems

Stephen Joe: Error estimation for lattice rules

Paul B. Bailey: Computing Sturm-Liouville eigenvalues for general limit circle boundary conditions

T. E. Simos and G. V. Mitsou: Runge-Kutta-Nystrom methods for the numerical integration of special second order initial value problems with oscillating solutions (presented by John Butcher)

PLENARY LECTURE

Ian Sloan: Numerical integration in high dimensions: the lattice rule approach